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(54) **METHOD FOR FABRICATING
MICROELECTRONIC DEVICES WITH
ISOLATION TRENCHES PARTIALLY
FORMED UNDER ACTIVE REGIONS**

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H01L 21/265

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,445,356 B1 * 5/2013 Cai H01L 21/76232
257/374

2005/0124102 A1 * 6/2005 Wang H01L 21/76237
438/197

(Continued)

OTHER PUBLICATIONS

U.S. Appl. No. 14/425,977, filed Mar. 4, 2015, Vinet, et al.

(Continued)

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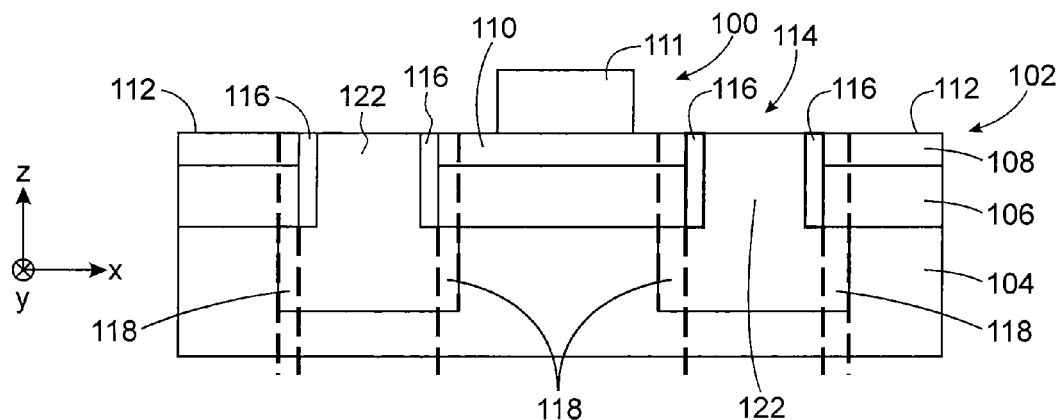
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(57) **ABSTRACT**

A method of producing a microelectronic device in a substrate comprising a first semiconductor layer, a dielectric layer and a second semiconductor layer, comprising the following steps: etching a trench through the first semiconductor layer, the dielectric layer and a part of the thickness of the second semiconductor layer, thus defining, in the first semiconductor layer, one active region of the microelectronic device, ionic implantation in one or more side walls of the trench, at the level of the second semiconductor layer, modifying the crystallographic properties and/or the chemical properties of the implanted semiconductor, etching of the implanted semiconductor such that at least a part of the trench extends under a part of the active region, —filling of the trench with a dielectric material, forming an isolation trench surrounding the active region and comprising portions extending under a part of the active region.

12 Claims, 6 Drawing Sheets



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- (51) **Int. Cl.** 2011/0193193 A1* 8/2011 Dube H01L 21/76229
H01L 21/84 (2006.01) 257/532
H01L 21/3065 (2006.01) 2013/0341649 A1 12/2013 Le Tiec et al.
H01L 21/308 (2006.01) 2014/0061798 A1 3/2014 Vinet et al.
H01L 21/265 (2006.01) 2014/0322767 A1 10/2014 Marchand et al.
H01L 21/306 (2006.01) 2015/0044841 A1 2/2015 Batude et al.
2015/0056734 A1 2/2015 Grenouillet et al.
- (52) **U.S. Cl.** OTHER PUBLICATIONS
CPC *H01L21/3065* (2013.01); *H01L 21/3086*
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21/76224 (2013.01); *H01L 21/76232*
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- (56) **References Cited**
U.S. PATENT DOCUMENTS
2007/0278183 A1* 12/2007 Lee H01L 21/30608
216/83
2009/0162991 A1 6/2009 Beneyton et al.
2009/0170331 A1 7/2009 Cheng et al.
2009/0289291 A1 11/2009 Cheng et al.
- U.S. Appl. No. 14/791,713, filed Jul. 6, 2015, Reboh, et al.
“International Business Machines Corporation; Patent Issued for
Method of Fabricating a Deep Trench (DT) Metal-Insulator (MIM)
Capacitor”, Journal of Engineering, (Aug. 29, 2012), (Total 5
Pages).
Written Opinion of the International Searching Authority Issued
Nov. 15, 2012 in PCT/US12/53768 Filed Sep. 5, 2012.
International Search Report Issued Nov. 15, 2012 in PCT/US12/
53768 Filed Sep. 5, 2012.
U.S. Appl. No. 14/441,354, filed May 7, 2015, Vinet, et al.
U.S. Appl. No. 14/719,580, filed May 22, 2015, Grenouillet, et al.
- * cited by examiner

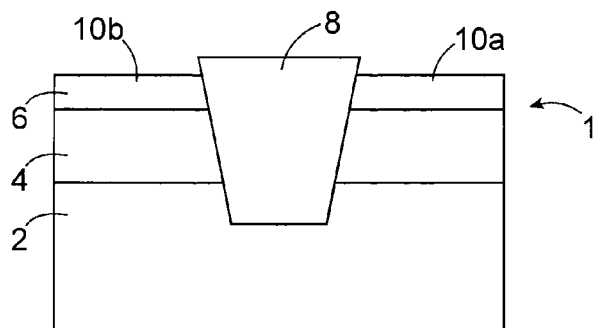


FIG. 1

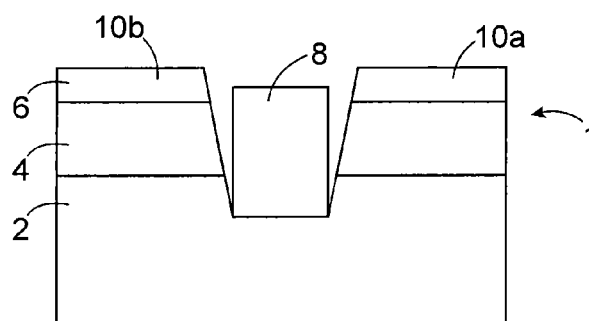


FIG. 2

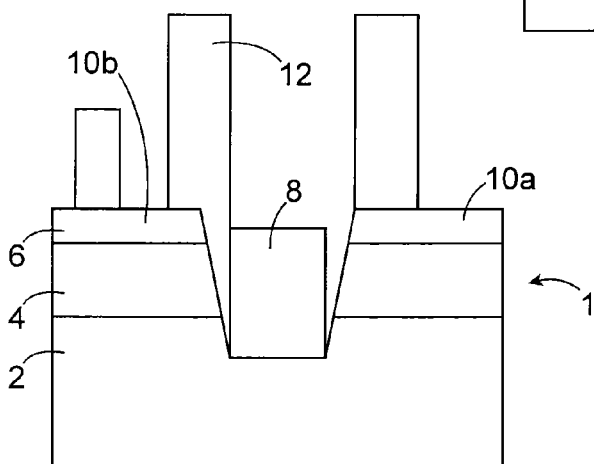


FIG. 3

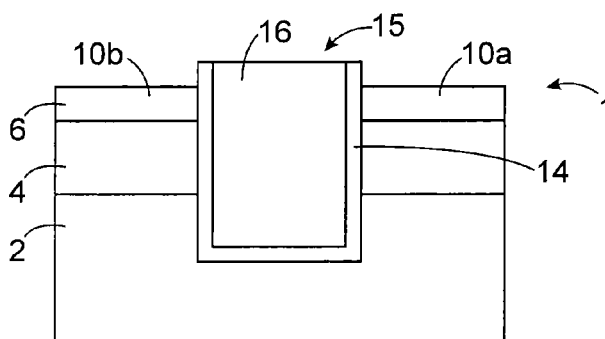
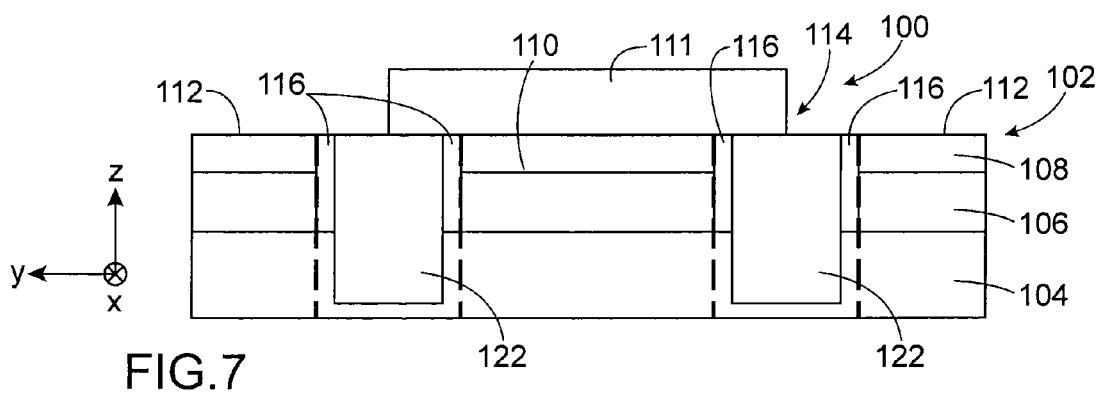
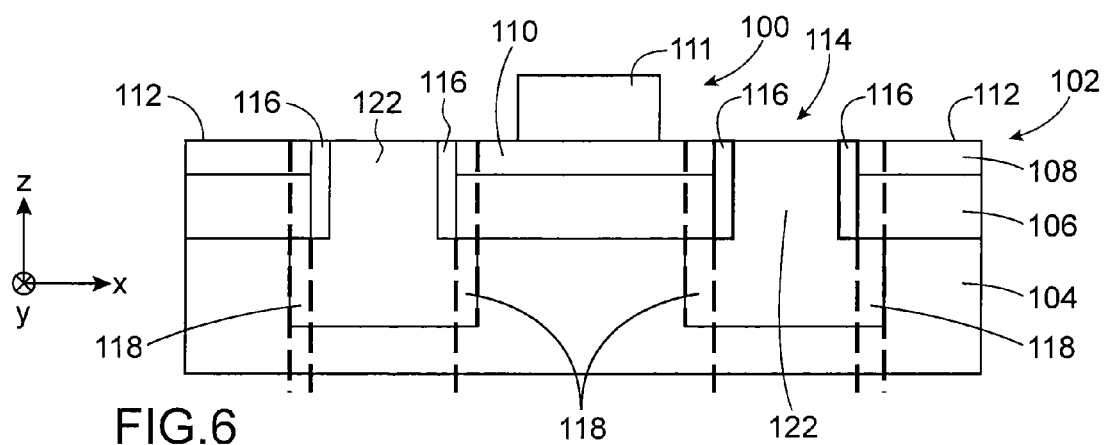
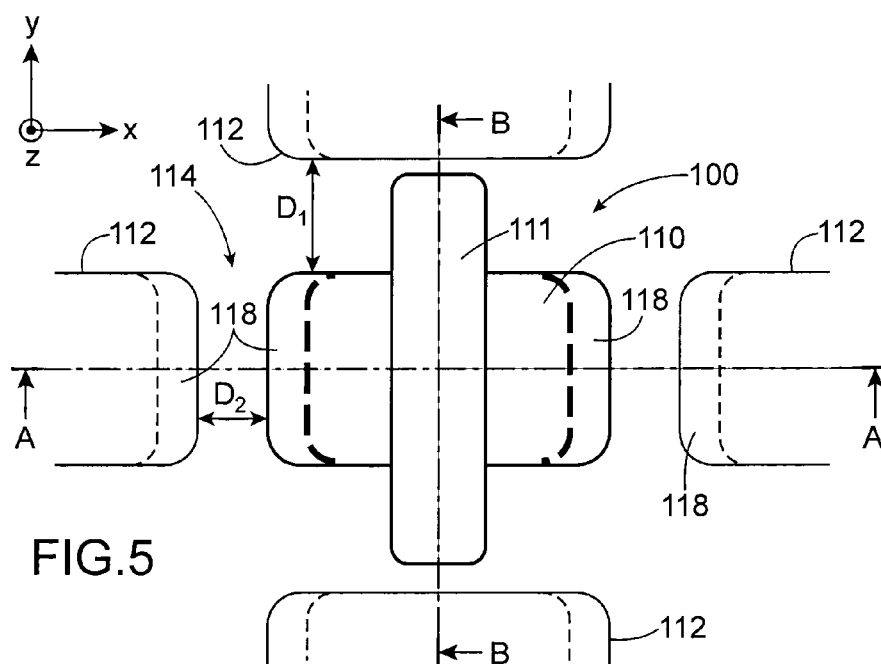


FIG. 4



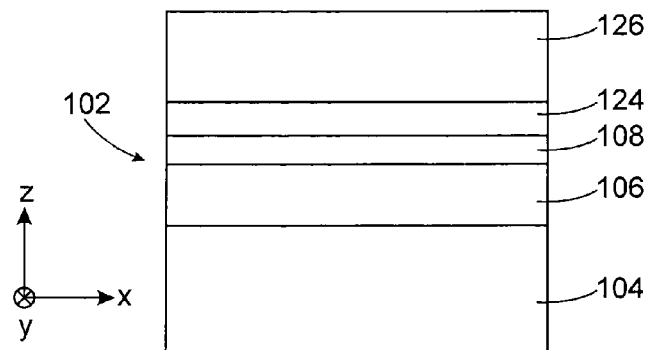


FIG. 8

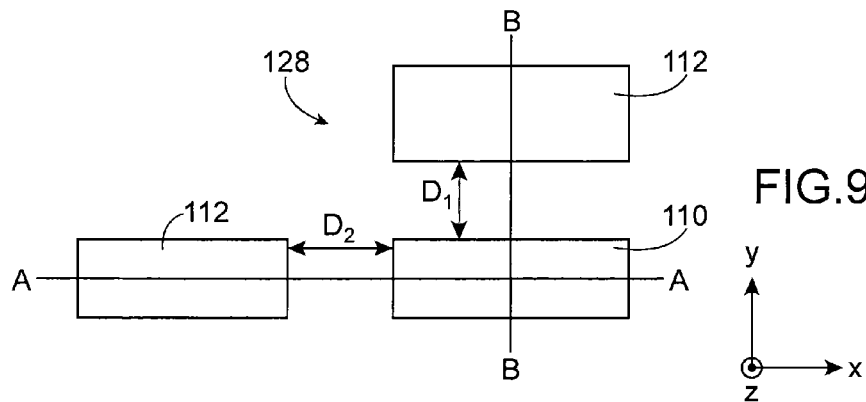


FIG. 9A

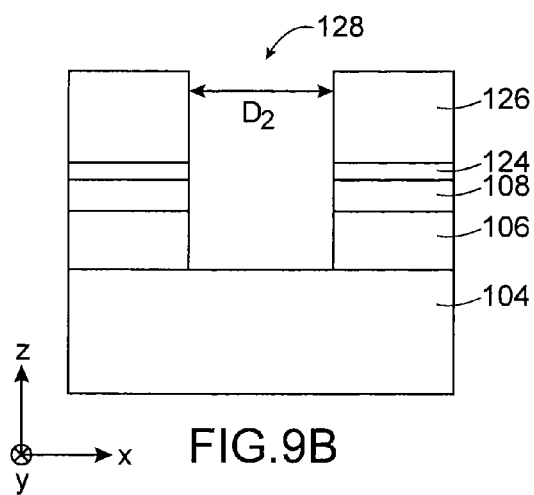


FIG. 9B

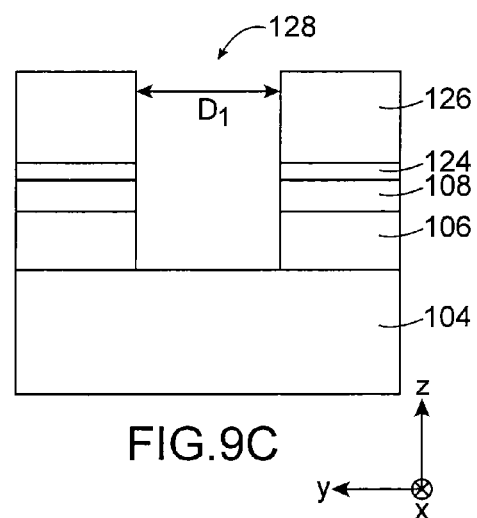
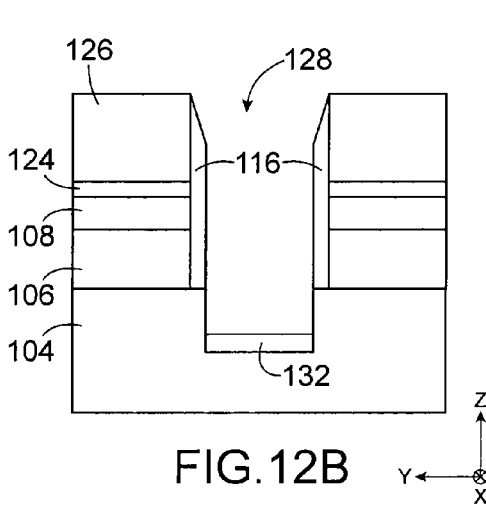
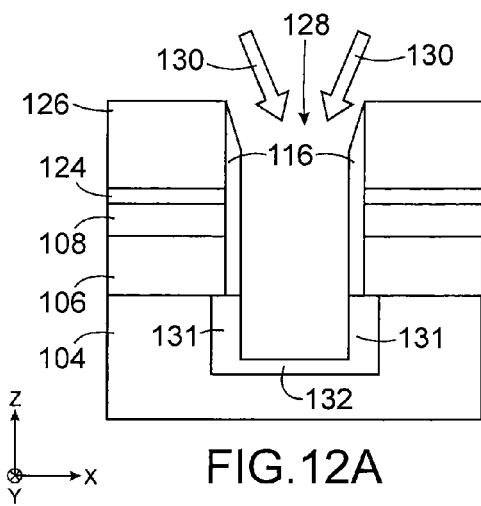
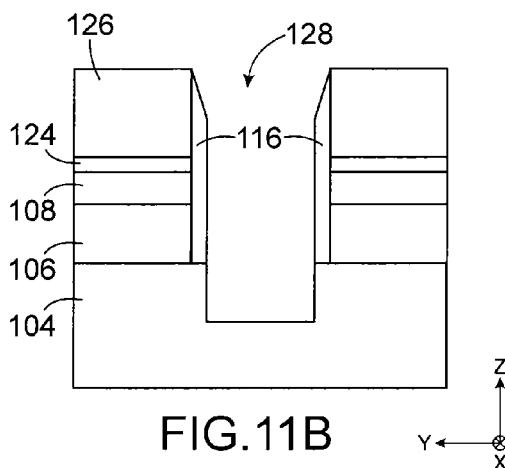
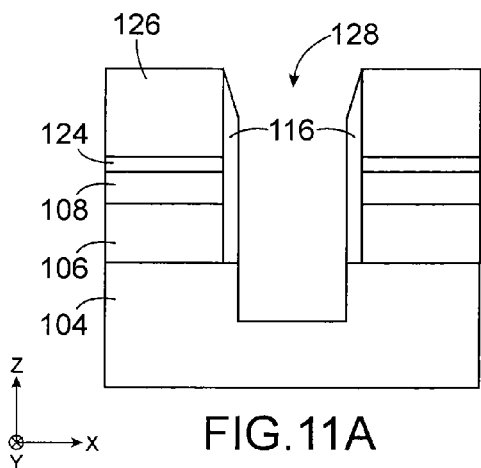
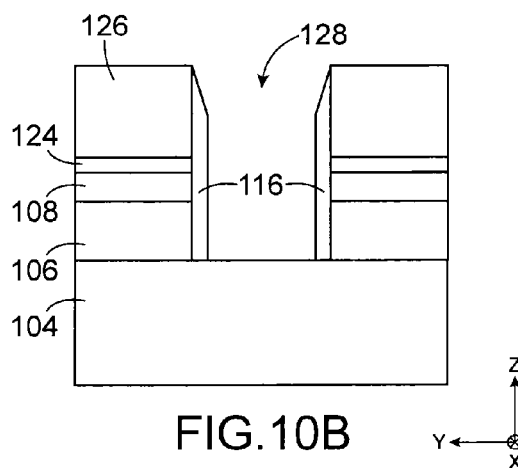
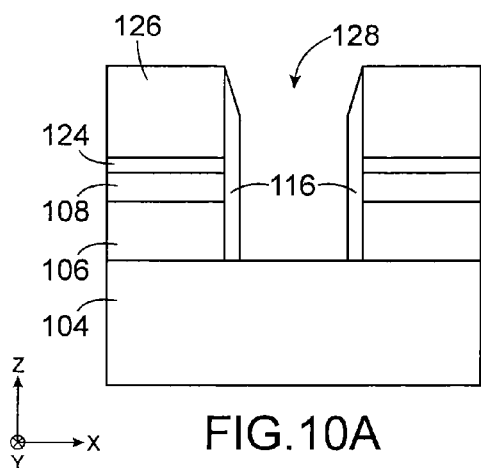


FIG. 9C



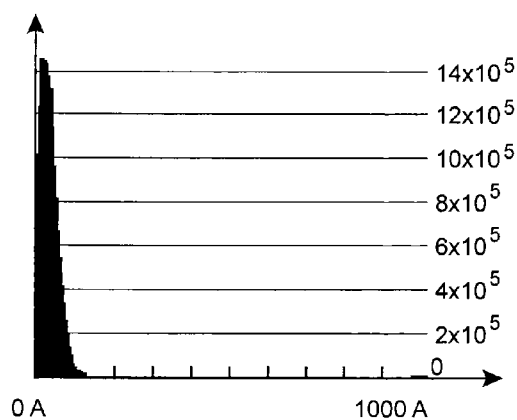


FIG. 13A

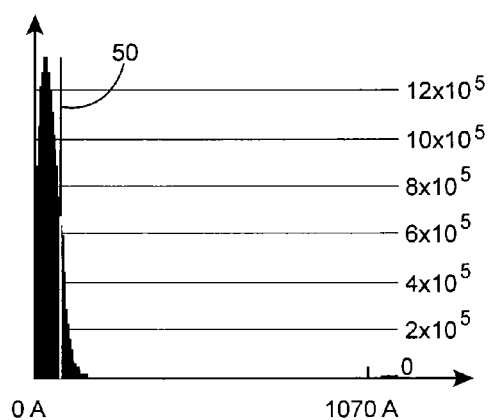


FIG. 13B

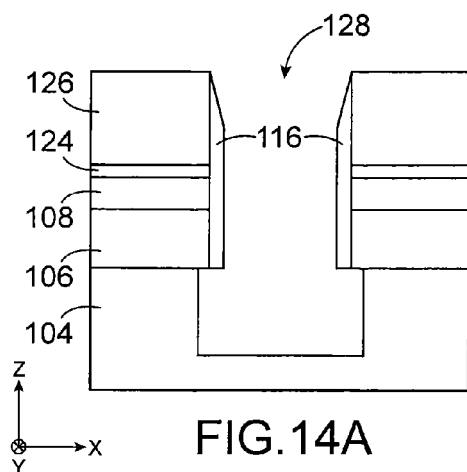


FIG. 14A

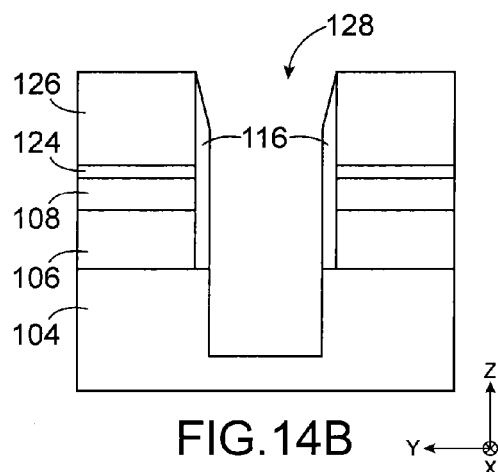


FIG. 14B

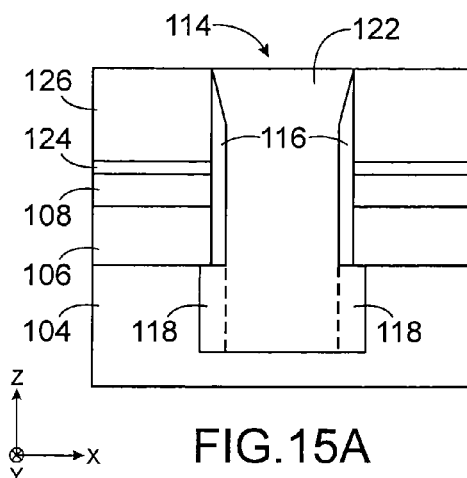


FIG. 15A

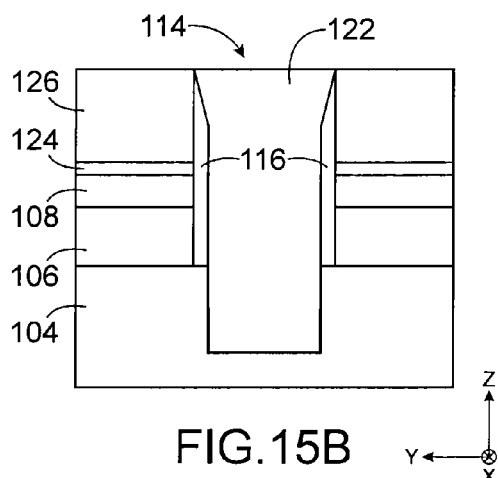


FIG. 15B

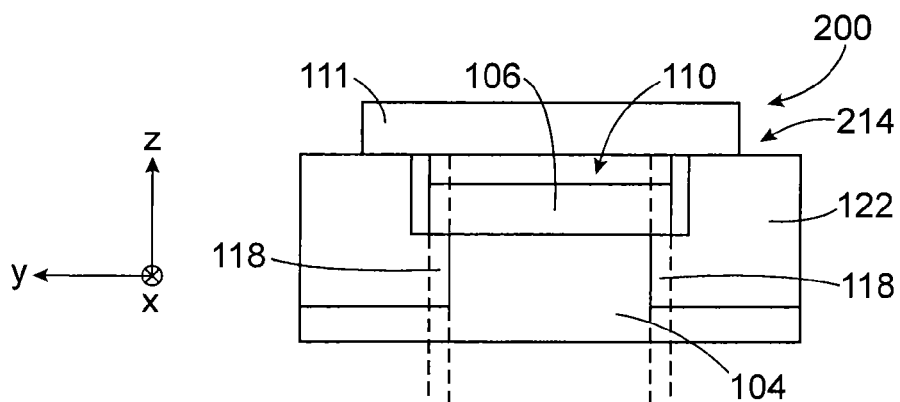
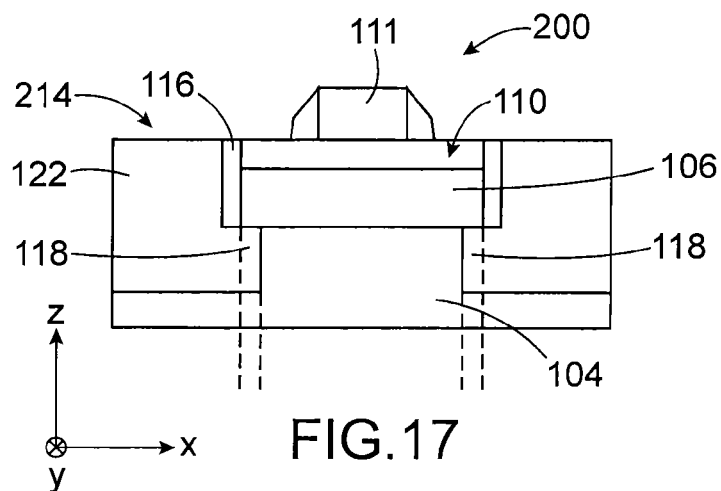
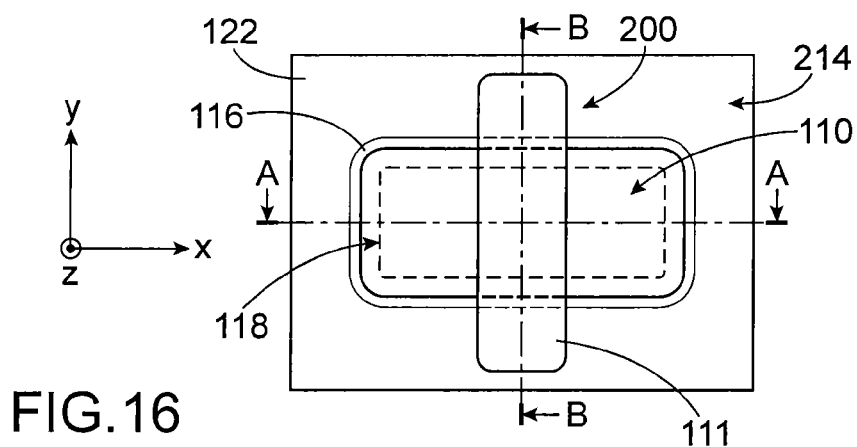


FIG. 18

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METHOD FOR FABRICATING MICROELECTRONIC DEVICES WITH ISOLATION TRENCHES PARTIALLY FORMED UNDER ACTIVE REGIONS

TECHNICAL FIELD

The invention relates to microelectronic devices fabricated with a semiconductor on insulator type substrate (SOI) and having active regions, or areas or zones, delimited by isolation trenches, for example of STI type ("Shallow Trench Isolation"). The invention is advantageously used for the production of FDSOI transistors (Fully-Depleted SOI) made with UTBB technology ("Ultra-Thin Body and Box").

BACKGROUND OF THE INVENTION

The fabrication of microelectronic devices, such as transistors, in a SOI substrate comprises the realization of insulation trenches, for example of the STI type, that allow an electrical isolation of the active regions of the devices, made in the same SOI substrate, from each other.

The pattern of the isolation trenches made in the substrate is complementary to that of the active regions of the devices. An example of an isolation trench **8** of the STI type is shown in FIG. **1**. This trench **8** is made in an SOI substrate **1** comprising a support layer **2**, or thick layer, composed of semiconductor (typically of silicon) coated with a dielectric thin layer **4** called BOX (Buried OXide) and a thin layer **6**, or surface layer, composed of semiconductor, here of silicon, and wherein the active regions of the devices are intended to be made. The isolation trench **8** bounds here two active regions **10a** and **10b** of two transistors made in the semiconductor thin layer **6**. The isolation trench **8**, composed of a dielectric material such as SiO₂, is made through the entire thicknesses of the semiconductor thin layer **6** and of the dielectric thin layer **4**, and a part of the thickness of the support layer **2**.

During the fabrication of the microelectronic devices in the substrate **1**, after forming the isolation trench **8**, the substrate **1** usually undergoes several steps of cleaning and etching which can damage the insulation trench **8**, such as cleaning steps performed with a hydrofluoric acid solution and after a gate etching or prior to silicidation or epitaxy steps. The semiconductor oxide of the isolation trench **8** is attacked by these steps and partially removed, both vertically and horizontally (see FIG. **2** onto which the dielectric material of the isolation trench **8** is partially withdrawn). Such degradations of the isolation trench **8** can lead to problems of electrical insulation between the support layer **2** and the thin layer **6**, especially during the subsequent realization of electrical contacts in the vicinity of the isolation trench **8**. In the example shown on FIG. **3**, one of the electrical contacts **12** is intended to electrically contact a portion of the active region **10b** near the isolation trench **8**, this portion corresponding for example to a source or drain region of a transistor made in the active region **10b**. However, in current technology nodes, given the short distance between two active regions (equal to about 50 nm in the 20 nm-node technology) which corresponds to the width of the isolation trench, a slight misalignment during the lithography made to form the electrical contact **12** can cause a shift of this electrical contact **12** on the isolation trench **8**. Such a shift can also be intentional, some electrical contacts being made voluntarily overflowing on the isolation trench **8**. However, given the partial withdrawal of SiO₂ of the isolation trench **8**, this offset can lead to a short circuit between

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the active region **10b** formed in the semiconductor thin layer **6** and the semiconductor of the support layer **2** (on the example of FIG. **3**, a part of the electrical contact **12** is placed in a recess formed by the partial removal of the dielectric material of the isolation trench **8**, thus short-circuiting the thin layer **6** with the support layer **2**).

To solve this problem of degradation of the insulation trenches, a solution shown in FIG. **4** is, when performing an isolation trench **15**, first to cover the walls (side walls and bottom wall) of the trench with a thin layer **14** (a liner) composed of a dielectric material more resistant than the semiconductor oxide used to make the isolation trench **8**, for example silicon nitride. The remaining space of the trench is then filled with a semiconductor oxide **16**, like SiO₂.

The parts of the SiN layer **14** forming the side walls of the isolation trench **15** strengthen the resistance of the isolation trench **15** towards the steps of cleaning and etching.

However, although this solution partially avoids degrading the isolation trench during the steps of cleaning and etching, it does not completely eliminate the risk of short circuit described above. Indeed, during the etching of the electrical contacts, it is necessary to etch a thin nitride layer (called "contact etch stop layer"), which will result in the simultaneous etching of the nitride layer **14** and thus destroy the sealing made by the nitride layer **14**. In addition, when the layer **14** is composed of a high permittivity dielectric, electrical performance degradations are observed as a result of an oxygen diffusion occurring through the liner.

BRIEF DESCRIPTION OF THE INVENTION

One aim of the present invention is to provide a method of producing a microelectronic device comprising at least one active region delimited by an isolation trench that is resistant towards of steps which can degrade the material(s) of the isolation trench, which avoids short circuits in the substrate even in case of partial withdrawal of the material (s) of the trench isolation, and which enables to obtain a bottling process not limited by the dimensions and the shape of the isolation trench.

For this, the present invention proposes a method of producing a microelectronic device in a substrate comprising a first semiconductor layer disposed on a dielectric layer, the dielectric layer being disposed on a second semiconductor layer, comprising at least the following steps:

- etching a trench through the first semiconductor layer, the dielectric layer and a part of the thickness of the second semiconductor layer, thus defining, in the first semiconductor layer, at least one active region of the microelectronic device,
- ionic implantation in one or more side walls of the trench, at the level of the second semiconductor layer, modifying the crystallographic properties, or the chemical properties, or both the crystallographic properties and the chemical properties, of the implanted semiconductor,
- etching of the implanted semiconductor such that at least a part of the trench extends under a part of the active region,
- filling of the trench with a dielectric material, forming an isolation trench surrounding the active region and comprising portions extending under a part of the active region.

Thus, the isolation trench comprises, at the level of the support layer of the substrate, that is the second semiconductor layer, one or more dielectric regions thicker than the rest of the isolation trench and which extend under the active

region, for example where there is a risk of short circuit and/or where the thickness of the dielectric material of the isolation trench has no or little impact on the electrical characteristics of the semiconductor device, for example under the regions of source and drain of a transistor which may correspond to the microelectronic device. In the event of partial withdrawal of a part of the dielectric material of the isolation trench, the thicker dielectric regions ensure an electrical insulation of the second semiconductor layer towards of one or more electrical contacts which may extend beyond over the isolation trench.

Such isolation trench therefore comprises one or more side walls which, at the level of the second semiconductor layer, are not vertically aligned with the active region bounded by the isolation trench.

The use of the ionic implantation in order to modify the crystallographic properties of the semiconductor (crystalline vs. amorphous) and/or the chemical properties (semiconductor vs. compound comprising this semiconductor) to obtain an etching selectivity of this implanted semiconductor in view of the rest of the semiconductor of the thick layer. This method also enables to obtain a bottling process, that is a local enlargement of the dielectric of the isolation trench at the level of the second semiconductor layer, which does not depend on the loading factor, i.e. which does not depend on the density of the design realized in the silicon wafer.

The portions of the isolation trench which extend under the part of the active region may be in contact with a portion of the dielectric layer disposed under the active region.

The semiconductor of the second semiconductor layer may be crystalline, and the ionic implantation in said one or more side walls of the trench may be such that the implanted semiconductor become amorphous.

The ionic implantation in said one or more side walls of the trench may be such that the implanted semiconductor become a compound of said semiconductor and of the implanted ionic species.

The etching of the implanted semiconductor may be made using HCl as etching agent.

The ionic implantation may be carried out with at least one ion beam having an energy of between about 0.5 keV and 40 keV, and/or a dose between about $5 \cdot 10^{13}$ and $5 \cdot 10^{16}$ at cm^{-2} , and/or oriented such that an angle between said one or more side walls of the trench and the ion beam is between around 5° and 25° . The energy of the ion beam may be preferably between about 0.5 keV and 10 keV to avoid significant changes of physical properties of the first semiconductor layer. Using ion beams with low energy and moderate dose reduces the risk of defects and dislocations in the implanted semiconductor. In addition, the implantation may be carried out in only one direction so that only a part of the side walls of the isolation trench extends under the active region.

The ionic implantation may also be performed in a bottom wall of the trench.

The method may further comprises, between the step of etching the trench and the step of ionic implantation, a step of producing at least one dielectric layer forming side walls of the isolation trench against the dielectric layer and the first semiconductor layer. Such a liner may form the upper part of the side walls of the isolation trench.

The active region may be substantially rectangular in shape and bounded by at least four side walls of the isolation trench extending through the first semiconductor layer, the dielectric layer and said part of the thickness of the second semiconductor layer, and wherein, at the level of said part of the second semiconductor layer conductor, two of the four

side walls which are substantially parallel with respect to each other extend under a part of the active region and the two other side walls do not extend under the active region. Thus, such isolation trench comprises an asymmetrical profile such that at the level of the second semiconductor layer (that is the support layer of the substrate), the two side walls which extend under the active region avoid short circuits in the substrate even in the case of partial withdrawal of the materials of the isolation trench.

In this case, the method may further comprise, after the step of filling of the trench, a step of producing at least one transistor in the active region, the transistor comprising a gate made on a part of the active region and on a part of said two other side walls. The side walls which are oriented substantially perpendicular to the gate may correspond to those which do not extend under the active region (and in particular under the channel region of the transistor), and which are aligned vertically with the active region so as to not reduce the size of the ground plane of the transistor, and therefore does not shift the threshold voltage of the transistor from its nominal value. Moreover, this configuration also limits the degradation of short channel effects because the thickness of the dielectric which is buried under the channel is not changed.

The active region may be substantially rectangular in shape and bounded by side walls of the isolation trench extending through the first semiconductor layer, the dielectric layer and said part of the thickness of the second semiconductor layer, and wherein, at the level of said part of the second semiconductor layer conductor, the side walls extend under a part of the active region. In this variant, at the level of the second layer of semiconductor, all side walls of the isolation trench may extend beyond under the active region, and be in contact with a portion of the dielectric layer which is disposed under the active region. Thus, in this variant, at the level of the second semiconductor layer, none of the side walls of the isolation trench at the level of the second semiconductor layer is vertically aligned with the bounds of active region delimited by the part of the isolation trench at the level of the first semiconductor layer.

The method may further comprise, after the step of filling of the trench, a step of producing at least one transistor in the active region, the transistor comprising a gate made on a part of the active region.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be better understood upon reading the description of embodiments given purely indicative and in no way limiting with reference to the accompanying drawings, in which:

FIGS. 1 to 4 show isolation trenches according to prior art;

FIGS. 5 to 7 show a microelectronic device produced with a method according to a first embodiment of the invention;

FIGS. 8 to 15B show steps of a method of producing a microelectronic device according to the first embodiment of the invention,

FIGS. 16 to 18 show a microelectronic device produced with a method according to a second embodiment of the invention.

Identical, similar or equivalent parts of the different figures described hereinafter bear the same numerical references so as to facilitate the transition from one figure to another.

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The different parts illustrated in the figures are not necessarily shown using a uniform scale, to make the figures more legible.

The different possibilities (alternatives and embodiments) must be understood as not being mutually exclusive and may be combined with one another.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

Referring first to FIGS. 5-7 which show schematically a microelectronic device **100**, here a FDSOI transistor of the UTBB type, produced with a method according to a first embodiment which will be further described. FIG. 5 is a top view of the transistor **100**, and FIGS. 6 and 7 are cross-sectional views respectively along lines AA and BB shown in FIG. 5.

The transistor **100** is produced in a substrate **102** of SOI type comprising a support layer **104**, or thick layer, composed of semiconductor, for example composed of silicon, a dielectric thin layer **106** (BOX), for example composed of SiO₂, and a thin layer **108**, or surface layer, composed of semiconductor, here silicon. A region of the semiconductor thin layer **108** forms an active region **110** of the transistor **100** comprising a channel, a source region and a drain region of the transistor **100**. A gate **111** of the transistor **100** is formed on the active region **110**.

Other active regions **112** of different devices are also made in the substrate **102** and shown in FIGS. 5-7. The active region **110** is isolated from the other active regions **112** by an isolation trench **114** the design of which being complementary to that of all the active regions made in the substrate **102**. The distance between two active regions (corresponding to the distances D₁ and D₂ shown in FIG. 5) corresponds to the width of the isolation trench **114**, and is for example between about 40 nm and 1 μm. For microelectronic devices made with 20 nm-node technology, the width of the isolation trench **114** is for example between about 40 nm and 200 nm. The isolation trench **114** bounds the active region **110**.

The isolation trench **114** is made through the entire thickness of the semiconductor thin layer **108** and of the dielectric thin layer **106**, and through a part of the thickness of the semiconductor support layer **104**. At the level of the semiconductor thin layer **108** and of the dielectric thin layer **106**, the side walls of the isolation trench **114** are formed by a dielectric layer **116** composed of nitride semiconductor, here SiN, or a bilayer of SiN/SiO₂, or a high-k dielectric (with a permittivity greater than about 3.9) such as HfO₂ or HfSiON. This dielectric layer **116**, whose thickness is for example between about 5 nm and nm, in particular allows to prevent, during the realization of the isolation trench **114** which will be described below, a ionic implantation in the semiconductor of the thin layer **108**. For reasons of clarity of the drawings, the layer **116** is not visible in FIG. 5.

At the level of the support layer **104**, the side walls of the isolation trench **114** are formed by portions of dielectric material, here SiO₂, whose thickness varies depending on the orientation of these walls towards the gate **111** of the transistor **100**. Indeed, around the active region **110** which is rectangular in shape, the isolation trench **114** has four side walls which are parallel in pairs. At the level of the side walls of the isolation trench **114** which are not covered by the gate **111**, that is to say that do not cross the gate **111** (these side walls being oriented parallel to the grid **111** which spreads along a direction corresponding to the Y axis in FIGS. 5 to 7, that is the grid has main sides parallel to this

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direction which corresponds to the Y axis), dielectric portions **118** which have a thickness (dimension along the X axis) between about 5 nm and 10 nm form the side walls of the isolation trench **114** in the semiconductor support layer **104** under active regions **110**, **112**. According to other variants, the thickness of the dielectric portions **118** may be between about 5 nm and 50 nm. These portions **118** are arranged under the active region **110** (see FIG. 6). The portions **118** are in contact with the part of the dielectric layer **106** located under the active region **110**. The portions of dielectric material **118** forming two side walls of the isolation trench **114** are represented symbolically in broken lines in FIG. 5.

The remainder of the isolation trench **114** is filled with a dielectric material **122**, such as SiO₂. Thus, at the level of the side walls of the trench which are oriented perpendicularly to the gate **111**, the dielectric material **122** form the side walls of the isolation trench **114** at the level of the support layer **104** of semiconductor and is not arranged under the active region **110**.

A method for producing the microelectronic device **100**, here a transistor FDSOI, according to the first embodiment is now described in relation with FIGS. 8-15.

The transistor **100** is made from a standard pre-STI stack comprising the SOI substrate **102** onto which are stacked an oxide layer (e.g. SiO₂) **124** and a nitride layer (here SiN) **126**. The layers of this stack shown in FIG. 8 have here the following thicknesses:

- nitride layer **126**: 80 nm, or between around 50 nm and 100 nm,
- oxide layer **124**: 10 nm, or between around 3 nm and 10 nm,
- thin layer of silicon **108**: 7 nm,
- thin dielectric layer **106**: 25 nm,
- thick silicon layer **104**: 700 μm.

The thicknesses given above are given as an indication for a transistor **100** manufactured using the 20 nm-node UTBB technology. However, these thicknesses may vary, according to the implementation options considered and also the technology node with which the device is made.

A trench **128**, whose design is complementary to that of the active regions to achieve in the substrate, is etched through the nitride layer **126**, the oxide layer **124**, the thin layer of semiconductor **108** and the thin dielectric layer **106** (but not through the thick layer **104**). In the example of FIGS. 9A to 9C (FIGS. 9B and 9C are cross-sectional views respectively along the lines AA and BB shown in FIG. 9A), the active region **110** of the transistor **100** is spaced from the other active regions **112** of a distance D₁ or D₂ between about 40 nm and 50 nm, corresponding to the width of the trench **128**. This etching may correspond to an anisotropic etch with a stop at the level of the interface between the support layer **104** and the thin dielectric layer **106**.

The side walls of the trench **128** are then protected with the dielectric layer **116** composed for example of nitride semiconductor, here SiN, and produced against the side walls of the trench **128** (see FIGS. 10A and 10B). The dielectric layer **116** is formed as a spacer around the remaining portions of the layers **126**, **124**, **108** and **106**, that is against the side walls of the layers **126**, **124**, **108** and **106** located inside the trench **128**. The thickness of the dielectric layer **116** may be between around 3 nm and 15 nm for microelectronic devices made with 22 nm-node technology. The maximum thickness of the dielectric layer **116** depends on distance D₁ or D₂ which has to be respected according to the technology node with which the device is made. The dielectric layer **116** is produced with a conformal deposition

of the dielectric material (that is a deposition with a regular thickness against the sidewalls of the trench **128** and also against the bottom walls of the trench **128** and on the nitride layer **126**). An anisotropic etching, e.g. a RIE (Reactive Ion Etching), is then carried out in order to etch the portions of the dielectric material previously formed against the bottom walls of the trench **128** and on the nitride layer **126**, thus forming the dielectric layer **116** as a spacer around the portions of layers **126**, **124**, **108** and **106**.

According to another embodiment, the dielectric layer **116** may comprise a bilayer of SiN/SiO₂, or a high-k dielectric (with a permittivity greater than about 3.9) such as HfO₂ or HfSiON.

As shown in FIGS. **11A** and **11B**, the trench **128** is then extended through a part of the thickness of the semiconductor support layer **104**. In the example described here, the total depth of the trench **128** (through the layers **126**, **124**, **108**, **106** and **104**) is for example equal to about 200 nm, and may be between 100 nm and 300 nm.

As shown in FIGS. **12A** and **12B**, an ionic implantation is then carried out in the semiconductor of the layer **104** exposed in the trench **128**, that is in the walls of the layer **104** at the level of the trench **128**. This ionic implantation is carried out in order to locally modify the crystallographic properties and/or the chemical properties of the semiconductor (here silicon) of the layer **104** exposed in the trench **128**. This ionic implantation is implemented such that the crystallographic properties and/or the chemical properties of the semiconductor of the parts of the side walls of the trench **128** at the level of the thick layer **104** are transformed through a thickness which depends on the parameters of the ionic implantation. In the first embodiment described here, this implantation is performed only in the side walls which are parallel to the main dimension of the gate of the transistor **100**, that is to say, extending parallel to the Y axis. Thus, as represented in FIG. **12A**, portions **131** composed of semiconductor with modified crystallographic properties and/or chemical properties form these side walls. Such implantation is performed using ion beams **130** forming a zero angle with the plane (X, Z). Thus, the ion beam **130** does not perform a modification of the crystallographic properties and/or the chemical properties of the semiconductor at the level of the side walls of the trench **128** extending parallel to the axis X. The beams **130** form for example an angle equal to about 15° with the normal to the substrate **102** (that is to say an angle of about 15° with respect to the Z axis). The angle of beams **130** is adapted according to the depth of the trench **128** (e.g. 200 nm) and its lateral dimensions (width, e.g. 50 nm), and may be between about 5° and 30°.

The dielectric layer **116** formed along the side walls of the trench **128**, at the level of the layers **106**, **108**, **124** and **126** of the stack, protects these layers, and especially the thin silicon layer **108**, against the beams **130**, thereby preventing the ionic implantation in the silicon thin film **108**. By way of illustration, FIGS. **13A** and **13B** show the concentration ratios at cm⁻³/at cm⁻² obtained respectively in silicon (see FIG. **13A**) and in silicon covered with a layer of SiN with a thickness equal to about 6 nm (see FIG. **13B**), depending on the depth in the implanted materials. We see in FIG. **13B** that silicon (the reference **50** corresponds to the limit SiN/Si) does not undergo almost the implantation performed.

All the bottom wall of the trench **128**, that is also the bottom wall of the parts of the trench **128** extending parallel to the axis X, undergoes the ionic implantation in a similar manner to the side walls which extend parallel to the Y axis, at the level of the support layer of semiconductor **104**. Thus

portions **132** composed of semiconductor with modified crystallographic properties and/or modified chemical properties correspond to the bottom wall of the trench **128**.

According to the nature of the ionic species which are implanted in the semiconductor, the crystallographic properties and/or the chemical properties of the semiconductor are modified. According to a first variant, it is possible to implant ionic species such that the implanted semiconductor becomes amorphous. In this case, ionic species, such as for example argon and/or nitrogen (or eventually ionic species like arsenic and/or phosphorus if a n-type ground plane is desired), are implanted in the semiconductor (in this case, the substrate **102** comprises initially a thick layer **104** composed of crystalline semiconductor, and especially monocrystalline semiconductor in case of CMOS transistor). After the implantation, these species don't change the doping of the semiconductor and don't form an alloy based on the implanted semiconductor. The dose of implanted ionic species is chosen such that the implanted semiconductor become amorphous semiconductor, e.g. more the 5·10¹⁴ cm⁻². The table below gives the thickness (in nm) of the implanted semiconductor with beams of argon, with a tilt angle of 20°, for different values of the dose and of the energy of the beams, in silicon:

Dose (cm ⁻²)	Energy (keV)					
	2		4		8	
	a/c	Rp	a/c	Rp	a/c	Rp
5E+14	4.8	5.7	8.2	10.6	14.7	18.2
1E+15	5.7	5.3	10.1	9	18.1	15.3

The parameter "a/c" corresponds to the limit between amorphous/crystalline in the implanted semiconductor, that is corresponds to the lateral amorphization depth. The parameter "Rp" corresponds to the desired depth implantation.

Thus it is possible to chose the thickness of the implanted semiconductor (in FIG. **12A**, this thickness corresponds to the dimension along the X axis for the lateral portions **131**, and the dimension along the Z axis for the bottom portion **132**) by modifying one or several of the following parameters: dose, energy, nature of the implanted ionic species, angle of the ionic beams.

According to a second variant, it is possible to implant ionic species in the semiconductor such that this implantation creates a new compound of the semiconductor and of the implanted species. For example, it is possible to implant germanium and/or carbon in the semiconductor such that the portions **131** and **132** are composed of a compound of this semiconductor and of the implanted species (e.g. composed of SiGe and/or SiC if the layer **104** is composed of silicon). Moreover, in this second variant, according to the implantation dose, it is possible that this implantation also modify the crystallographic properties of the implanted material, which may be amorphous if the semiconductor is initially crystalline. For example, an implantation of germanium in crystalline silicon, with an energy of between 4 keV and 10 keV, and a dose equal to around 1E+16 cm⁻² leads to an portion of amorphous SiGe with a thickness equal to around 10 nm.

During the ionic implantation, a small part of the semiconductor of the thin layer **108**, at the level of the side walls of the trench **128** may become amorphous. However, this

part of amorphous semiconductor will become again crystalline during a further annealing made during the process, as described further.

The portions **131** and **132** of semiconductor with modified crystallographic properties and/or modified chemical properties are then removed as shown in FIGS. **14A** and **14B**. This removing can correspond to a vapor phase etching, or gaseous phase etching, using HCl as etching agent. When the ionic implantation corresponds to an implantation of neutral species like nitrogen, argon or arsenic, this etching is implemented for example at a temperature which is less than around 600° C., e.g. equal to around 550° C., and with a partial pressure of 30000 Pa (which may be between around 100 Pa and 10⁵ Pa) in order to have a re-crystallization speed which is lower than the etching speed (this re-crystallization corresponds to the amorphous semiconductor **131**, **132** which become again crystalline). When the implantation creates an alloy composed of the semiconductor and of the implanted species (for example germanium or carbon), the temperature of the etching step may be greater than 600° C. because the re-crystallization of portions **131**, **132** has no impact on the etching (even if the portions **131**, **132** become again crystalline, the chemical composition of the portions **131**, **132** remains different than that of the layer **102**). It is possible to etch portions **131** and **132** because the crystallographic and/or chemical properties of portions **131** and **132** are different than the crystallographic and/or chemical properties of the non-implanted semiconductor of the layer **104**. The previous step of implantation enables to obtain an etching selectivity between implanted portions **131**, **132** and the non-implanted semiconductor of the layer **104**. For example, the etching of amorphous silicon is around 100 times larger than the etching of monocrystalline silicon when HCl is used as etching agent. A small part of non-implanted semiconductor of the layer **104** may however be etched, as represented in FIG. **14B**. However, in this case, the etched part does not reach the region located under the active region.

For example, it is possible to implant argon in monocrystalline silicon with energy equal to around 8 keV, a dose equal to around 5·10¹⁵ cm⁻², and a tilt angle equal to around 15°. An etching with HCl at a temperature equal to around 590° C. enables to remove between around 5 nm and 10 nm of silicon under the future active region.

The making of the isolation trench is then achieved with the filling of the trench **128** with a dielectric material **122**, e.g. SiO₂. The portions of dielectric material which are found deposited outside of the trench are etched by performing a CMP for example, the dielectric layer **126** serving as a stop layer during the planarization. This filling forms the dielectric portions **118** symbolically shown in FIG. **15A** (symbolically because there is no physical difference or bound between the dielectric material of the portions **118** and the rest of dielectric material **122**).

An annealing of the obtained isolation trench is then carried out, for example at a temperature equal to around 1050° C. and during around 30 minutes.

The layers **124** and **126** are then removed in order to reveal the thin layer of semiconductor **108**. The various components of the transistor **100** are then made from the thin layer of semiconductor **108** (gate dielectric, gate, creation of source and drain regions, etc . . .).

FIGS. **16** to **18** show schematically a microelectronic device **200**, here a FDSOI transistor of the UTBB type, according to a second embodiment. FIG. **16** is a top view of the transistor **200**, FIGS. **17** and **18** are cross-sectional views respectively along lines AA and BB shown in FIG. **16**.

Compared to the previously described device **100** in which only two of the four side walls of the isolation trench **114** extend under the active region **110**, the four side walls of the isolation trench **214** of device **200** all extend under the active region **110**. The dielectric portions **118** are therefore present in the entire periphery of the active region **110**.

Such isolation trench **214** is achieved via a ionic implantation (according to the first or the second variant as disclosed previously) of all side walls of the trench at the level of the thick semiconductor layer **104**, for example analogously to the achievement of the portions **118** of transistor **100** described above. The dielectric portions **118** are in contact with the part of the dielectric layer **106** located under the active regions **110**.

The invention claimed is:

1. A method of producing a microelectronic device in a substrate comprising a first semiconductor layer disposed on a dielectric layer, the dielectric layer being disposed on a second semiconductor layer, the method comprising:

etching a trench through the first semiconductor layer, the dielectric layer and a part of the thickness of the second semiconductor layer such that another part of the thickness of the second semiconductor layer remains under a bottom wall of the trench, thus defining, in the first semiconductor layer, at least one active region of the microelectronic device;

performing ionic implantation in one or more side walls of the trench, at a level of the second semiconductor layer, modifying the crystallographic properties, or the chemical properties, or both the crystallographic properties and the chemical properties, of the implanted second semiconductor layer in said side walls;

etching the implanted second semiconductor layer such that at least a part of the trench extends under a part of the active region; and

filling the trench with a dielectric material, forming an isolation trench surrounding the active region and comprising portions extending under the part of the active region.

2. The method according to claim 1, wherein the portions of the isolation trench that extend under the part of the active region are in contact with a portion of the dielectric layer disposed under the active region.

3. The method according to claim 1, wherein the semiconductor of the second semiconductor layer is crystalline, and the ionic implantation in said one or more side walls of the trench is such that the implanted second semiconductor layer becomes amorphous.

4. The method according to claim 1, wherein the ionic implantation in said one or more side walls of the trench is such that the implanted second semiconductor layer becomes a compound of said semiconductor and of an implanted ionic species.

5. The method according to claim 1, wherein the etching of the implanted second semiconductor layer is made using HCl as etching agent.

6. The method according to claim 1, wherein the ionic implantation is carried out with at least one ion beam having an energy of between about 0.5 keV and 40 keV, and/or a dose between about 5.10¹³ and 5.10¹⁶ at.cm⁻², and/or oriented such that an angle between said one or more side walls of the trench and the ion beam is between around 5° and 20°.

7. The method according to claim 1, wherein the ionic implantation is also performed in the bottom wall of the trench.

8. The method according to claim 1, further comprising, between the step of etching the trench and the step of ionic

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implantation, a step of producing at least one dielectric layer forming side walls of the isolation trench against the dielectric layer and the first semiconductor layer.

9. The method according to claim 1,

wherein the active region is substantially rectangular in shape and bounded by at least four side walls of the isolation trench extending through the first semiconductor layer, the dielectric layer and said part of the thickness of the second semiconductor layer, and

wherein, at the level of said part of the thickness of the second semiconductor layer, two of the four side walls which are substantially parallel with respect to each other extend under a part of the active region and the two other side walls do not extend under the active region.

10. The method according to claim 1,

wherein the active region is substantially rectangular in shape and bounded by side walls of the isolation trench

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extending through the first semiconductor layer, the dielectric layer and said part of the thickness of the second semiconductor layer, and

wherein, at the level of said part of the thickness of the second semiconductor layer, the side walls extend under a part of the active region.

11. The method according to claim 9, further comprising, after the step of filling of the trench, a step of producing at least one transistor in the active region, the transistor comprising a gate made on a part of the active region and on a part of said two other side walls.

12. The method according to claim 1, further comprising, after the step of filling of the trench, a step of producing at least one transistor in the active region, the transistor comprising a gate made on a part of the active region.

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